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A Hardware-In-the-Loop Simulation and Test for Unmanned Ground Vehicle on Indoor Environment

Khalid bin Hasnan^a, Luhur Budi Saesar^{b,*} and Tutut Herawan^c

^{ab}*Faculty of Mechanical and Manufacturing Engineering, University Tun Hussein onn Malaysia, Parit Raja, 86400, Johor, Malaysia*

^c*Faculty of Computer System and Software Engineering, University Malaysia Pahang, Gambang26300, Pahang, Malaysia*

Abstract

In this paper, we present an alternative approach for analyzing performance and monitoring of unmanned ground vehicle (UGV) through a Hardware-in-the-loop (HIL) simulation. This approach is started by defined a mathematical model of kinematic-dynamic forces apply and sensor-actuator model that integrated in UGV for simulation. A novel hardware control architecture was built to meet the HIL simulation method. Both simulation model and hardware configurations are provided by MATLAB/simulink toolboxes. To verify the HIL system, 2 small fields was built for the real test. Moreover 3D virtual model of UGV and the environment test field was developed to ease the system monitoring. Finally from the tracking system, results show that the HIL simulation method combined with the real environment produce more information of parameter that influenced during the tests given.

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Keywords : Hardware-in-the-loop; Simulation; Simulink; Unmanned Vehicle; Telemetry; Visualization.

1. Introduction

Hardware-in-the-loop (HIL) simulation has widely used among automotive industry, traffic control and many other industry. HIL test became new trends in embedded system testing since they provide the advantageous factor for the one who use it, the factor such as cost, safety, duration, and feasibility which is to be sought for most industries. Not to miss researcher on robotics and unmanned vehicle area they already use this type of simulation testing too. Like [4,9] that use HIL test for testing unmanned air vehicle (UAV). Generally in HIL simulation test, a real environment condition did not applied during the

* Corresponding author. Tel.: +6013-7553953

E-mail address: luhurbudi@gmail.com

test [2,3,10]. In this work, we propose an alternative approach to include the real environment which represents by let the UGV moved in certain indoor condition.

The rest of this paper is organized as follow. Section 2 describes control architecture that used by UGV. Section 3 describes the hardware configuration from system for HIL test. Section 4 describes simulation model that used to model the UGV. Furthermore kinematics, dynamics and actuator model from UGV are discussed. Section 5 describes experimental procedure. Section 6 describes the results and discussion. Finally, the conclusion of this work described in section 7.

2. Control architecture

Shown in Fig.1. The control architecture from the system proposed. There are 2 major systems in this study, first is the system on the UGV and second one is the operator system. In the UGV system there are 2 main subsystems, first is the telemetry system that we build [8]. Second subsystem contains in UGV is a Motion control. The second system is the Operator System, a system that enabled us to monitoring and controlling the robot and also in here where the simulation was running to matched with the real performance of UGV in real environment.

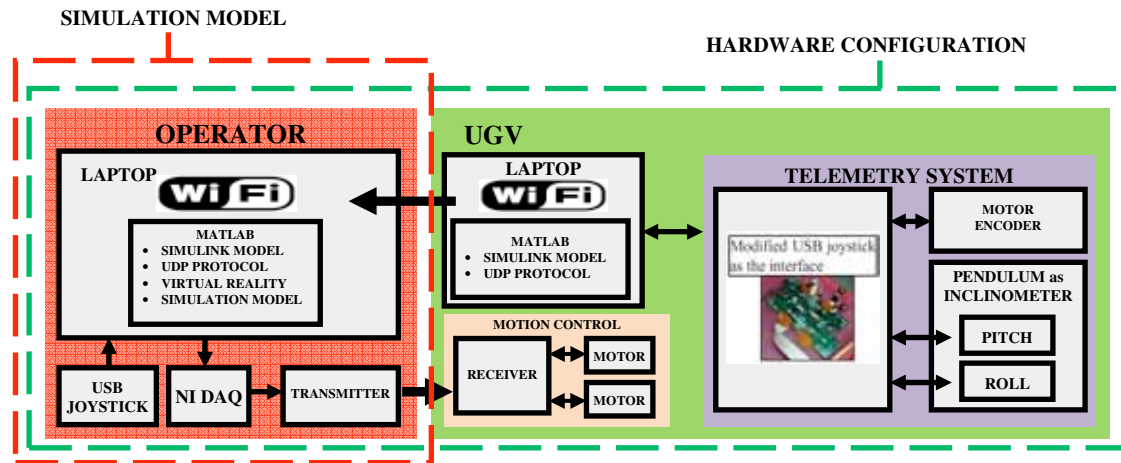


Fig.1. Control architecture

3. Hardware configuration

As shown in Fig.1. UGV moved by 2 motor that controlled by a joystick. With the help of Matlab/simulink toolboxes [5,7] and NI DAQ 6221, the digital signal input from joystick can be translated into analog signal to control UGV. There in UGV, 2 modified encoder and inclinometer [8] was installed to monitor movement and orientation of UGV. Later the data from encoder and inclinometer were sent from UGV through UDP protocol in simulink toolbox to the operator system.

4. Simulation model

The simulation test is provided in operator system. Here, inputs from USB joystick are directly sent to both the simulation and the hardware. In simulation side the signal inputs from joystick are assumed as the voltage given by the battery in reality. Later the voltage would affect the UGV simulation movement along with the kinematics-dynamics modeling that occur based on the assumption given.

4.1. Kinematics

Most models assume a wheeled mobile robot kinematics only experienced roll motion (rolling) [3]. Some of the assumptions used for the movement of pure rolling or rolling wheels, among others:

- Robot motion is modeled by a simple rigid body kinematics modeling
- Slip does not occur and the friction in the longitudinal direction of rolling movement between the wheels with the floor.

As shown in Fig.2 and adapted from [6], UGV moves on X-Y planes, $V = [uv\ 0]^T$ at its center of mass (COM). Where u is the longitudinal speed and v is the lateral speed. Since the motion is nonholonomic, $v=0$. However, it may rotate with an angular speed $\omega = [0\ 0\ r]^T$. If $\dot{q} = [\dot{X}\ \dot{Y}\ \dot{\theta}]^T$ is the state vector representing robot's X-Y. The lateral and angular speeds, u and r can be determined by having angular speeds on the left and right drive wheels, ω_l and ω_r

$$u = (\omega_r + \omega_l) \frac{R_t}{2} \tag{1}$$

$$\omega = r = (\omega_r - \omega_l) \frac{R_t}{T_r} \tag{2}$$

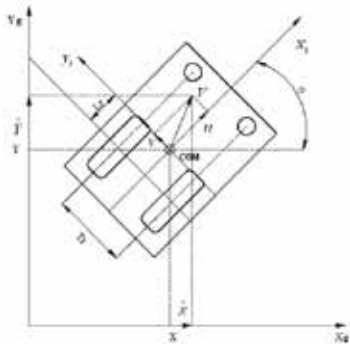


Fig2. Robot Orientation

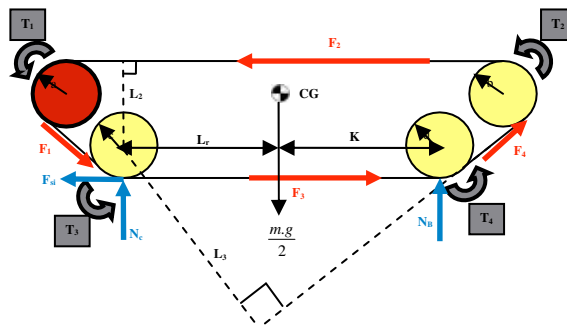


Fig3. Forces and Torsion on one side on tracked

4.2. Dynamics

The UGV has 1 drive wheel and 3 sprockets on each side as shown in Fig.3. The normal force N_c is.

$$N_c = \frac{k}{2(L_r + k)} m \cdot g \tag{3}$$

Total moment requires to accelerates the tracked consisting 1 drive wheel, 3 sprocket and a belt can be summary

$$\sum M_c = I_{roda} \cdot \alpha \left(2 + \frac{L_2 + L_3}{R_t} \right) \tag{4}$$

Where I_{wheels} is the effective wheel rotational inertia, to this the motor is needed to handle the torsional load.

$$T_L = \sum M_c + F_{si} R_t \tag{5}$$

4.3. Actuator

Two similar DC motors are assumed to move the UGV. Each motor is connected to the drive wheel on each side. The motor generates torsion

$$T_m(s) = K_i I_a(s) \tag{6}$$

Where K_i is the torque constant in Nm / A lb-ft / A, or oz-in / A. While the value of the load torque of the motor has been determined previously in Eq.5 in the discussion of modeling the dynamics of which are define as,

$$T_L(t) = \sum M_c(t) + F_{si}(t).R_t \tag{7}$$

Or can be state as

$$T_L(t) = I_{wheels} \left(2 + \frac{L_2+L_3}{R_t} \right) \frac{d\omega_m(t)}{dt} + T_{friction}(t) \tag{8}$$

Torsion reductions generated by the motor torque (T_m) with a load torque (T_L) will produce a total torque, which applied to the mechanical structures include the moment to drive the motor rotor inertia (J_m) and the moment of viscous friction and air friction bearings (B_m) that existed at motor mechanical load. Torque equation can be written as

$$J_m \frac{d\omega_m(t)}{dt} = T_m(t) - (T_L(t) + B_m \cdot \omega_m(t)) \tag{9}$$

Finally, after substitution Eq.8To Eq.9 the equation can be summarized to

$$(J_m + I_{wheels} \left(2 + \frac{L_2+L_3}{R_t} \right)) \frac{d\omega_m(t)}{dt} + B_m \cdot \omega_m(t) = T_m(t) - T_{friction}(t) \tag{10}$$

5. Experimental procedure

First calibrate the UGV movement (moving and turning), in this case calibrate the real signal comes from encoder on UGV with the parameter in simulink model. For example when UGV moved forward one meter how much signal read by encoder in simulink or when UGV rotate how much signal that represents 90° degrees rotation in reality. From there the accuracy of encoder to the real condition revealed and can be setup to simulink model. This UGV use only relative localization for knowing its local position. Odometry method were used here, where encoder act as a sensor to solve it.

Then place the real UGV and UGV model in the same coordinate for starter. After that, turn on the UGV and also run the simulation. Drive UGV through obstacle from the field to the finish spot without touching the field wall. After the UGV reach the finish spot, repeat it for different field and after the experiment finish, stop the software simulation and turn off the UGV.

6. Result and discussion



Fig 4. Real test field

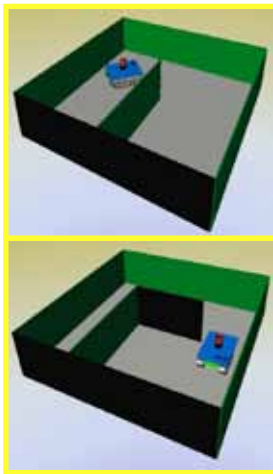


Fig5. Virtual environment

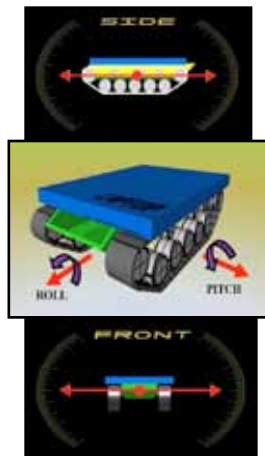


Fig6. UGV telemetry monitoring



Fig7. UGV Tracking results

As shown in Fig.4 that the real test from this study, with 2 types of field for the real test. Fig.5 shows 2 kind of field that used for this test in virtual reality environment and a UGV model also in virtual. Fig.6 shown the condition monitoring from UGV during the test based on the slope inclination from the pendulum and the orientation from the encoder.

The comparison of tracking result from UGV movement based on encoder reading in reality performance and in simulink during exploration field A and field B are shown in Fig.7. There Red dot represents as a UGV start point and purple dot as a finish point. The blue lines represent the real trajectory of UGV and the orange lines represent the movement of UGV in simulink model. Based on Fig.7 the blue line shapes smoother than the orange line. It means in reality the movement is smoother than in simulink. It caused by the sensitivity of the joystick in simulink while the test running and also from the friction and slip that may occur during the movement in reality.

7. Conclusion

In this paper, we have presented an alternative approach for analyzing performance and monitoring of UGV through a HIL simulation. By adding the real environment to the HIL simulation test gives more information how efficient are our kinematics-dynamics and actuator model deal with the real test and real hardware. From there the parameter that connects the simulation model and real hardware will reveal and it is very useful information for analysis in the future works and also it is an alternative approach that finally achieved for simulation and test of HIL method for UGV.

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References

- [1] Campion G., Bastin G. and D'Andrea-Novet B. (1996): Structural properties and classification of kinematic and dynamic models of wheeled mobile robots. — IEEE Trans.Robot. Automation, Vol. 12, No. 1, pp. 47–62.
- [2] D. Jung and P. Tsiotras, 2007. Modeling and hardware-in-the-loop simulation for a small unmanned aerial vehicle. American Institute of Aeronautics and Astronautics.
- [3] E. Johnson and S. Fontaine, "Use of flight simulation to complement flight testing of low-cost UAVs," AIAA Modeling and Simulation Technologies Conference, 2001.
- [4] G. Cai, B.M. Chen, T.H. Lee, and M. Dong. Design and implementation of a hardware-in-the-loop simulation system for small-scale uavhelicopters. *Mechatronics*, 19:1057–1066, 2009.
- [5] Hunt, B.R. "A Guide to Matlab for Beginner and Experienced Users". New York, Cambridge University Press, 2006.
- [6] J.D. Setiawan, M. Subchan, and A. Budiyo, "Virtual reality simulation of fire fighting robot dynamic and motion", ICIUS 2007, Oct 24-25, 2007, Bali, Indonesia.
- [7] Karris, S.T. "Introduction to Simulink with Engineering Application". USA: Orchard Publication, 2006.
- [8] L.B. Saesar, K. Hasnan and P.A. Yudhistira. A Framework of telemetry technology application in robotic area using MATLAB toolboxes for education. ICCAIE'10. IEEE International Conference, pages 418-423, Desember 2010.
- [9] N. R. Gans, W. E. Dixon, R. Lind, and A. Kurdila, "A hardware in the loop simulation platform for vision-based control of unmanned air vehicles," *Mechatronics*, vol. 19, pp. 1043-1056, 2009.
- [10] R. Isermann, J. Schaffnit, and S. Sinsel, "Hardware-in-the-loop simulation for the design and testing of engine control systems," *Control Engineering Practice*, vol. 7, pp. 643-653, 1998.